CLASSIFICATION OF LANDSCAPE GEOMETRY FOR MILITARY PURPOSES

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PREFACE

This paper was prepared for presentation at the Army Science Conference held on 20-22 June 1962 at the United States Military Academy, West Point, New York, and for publication in the proceedings of the conference.

The paper is based on work done for the Office, Chief of Engineers, and summarizes, in part, data published in Technical Report No. 3-506, "Handbook, A Technique for Preparing Desert Terrain Analogs," published at WES in May 1959.

KOLB

TITLE: Classification of Landscape Geometry for Military Purposes

CHARLES R. KOLB
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

ABSTRACT:

One of the most perplexing problems facing the military analyst in attempting to assess the effect of terrain on military activities is the qualitativeness of classical terrain description, particularly the configuration or geometry of the landscape. The lack of a useful and objectively oriented classification of landscape geometry is felt in almost all military terrain effects studies; e.g., estimating the impact of varying terrain types on airfield construction effort, correlating the results of vehicle trafficability data among widely separated areas, selecting sites for parachute-drop tests which reproduce conditions found in strategically or areally significant areas of the earth.

A method of classifying landscape based on relief, slope, slope occurrence, and plan-profile is presented. The interrelation of these parameters in landscape definition, modification in definition due to scale difference, and synthesis of these parameters in a single semiquantitative landscape symbolization are discussed. Landscape geometry classification is limited to terrain exhibiting more than 10 ft of relief. Terrain features exhibiting less than 10 ft of relief are classified as surface roughness or microrelief. The goal has been to develop as complete a landscape geometry definition as possible within as simple a framework as possible.

BIOGRAPHY:

PRESENT ASSIGNMENT: Chief, Geology Branch, WES

PAST EXPERIENCE: 1951 - Present, Member, Assistant Chief and Chief, Geology Branch, Army Engineer Waterways Experiment Station.

DEGREES HELD: Bachelor of Science, 1948, Master of Science, 1949, Ph.D., 1962, Louisiana State University.

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CHARLES R. KOLB
U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

Introduction

This paper outlines the method of classifying landscapes or terrain geometry developed at the U. S. Army Engineer Waterways Experiment Station, Corps of Engineers (WES). The classification was developed as part of a more comprehensive system of terrain description used to compare the terrain at the Research and Development Test Station at Yuma, Arizona, with the terrain of various desert areas throughout the world. Limited numbers of map-folio reports have been prepared which utilize this classification in mapping the desert regions of Northwest Africa, Northeast Africa, the Middle East, South Central Asia, Southwest United States, and Mexico. Details of the mapping techniques, the complete terrain classification, and the methods used to prepare terrain analogs are contained in WES Technical Report No. 3-506, A Technique for Preparing Desert Terrain Analogs, June 1959.

In this paper terrain is considered to be the sum of the various physical attributes of the land that describe an area. A terrain factor is an attribute of terrain such as slope, relief, etc. The effect of such a factor or of a combination of factors on an individual military activity, such as cross-country movement, air-drop potential, etc., is a terrain effect. A factor family is a convenient grouping of terrain factors. In the WES studies five factor families are considered: landscape geometry, microrelief, surface composition and consistency, hydrography, and vegetation. A mapping unit is a specific class of values or a definable subdivision of a terrain factor. For example, relief is a terrain factor and 0-10 ft of relief is a mapping unit.

Basis for Classification

General

Landscape geometry is the configuration or geometry of the landscape without regard to the vegetation that grows on it or the soil or rock type of which it is composed. It is an attribute of terrain that has long been qualitatively and imprecisely categorized in terms such as hilly, mountainous, rolling, etc. But what may be hilly to the mountaineer may be mountainous to the flatlander. Also, the same landscape may be described by one observer using one set of terms, and by another observer--or even the same observer at a later date--using an entirely different set of terms. Because there is no uniform system of description, the observer is forced to use qualitative terminology that varies to suit the occasion. Few deny the need for a precise, quantitative description of terrain. Such a description is essential if widely separated areas are to be compared, and if the effect of the configuration of the landscape on various military activities is to be critically assessed. This would in turn improve the application of operational and testing experience to other areas of the world, and make possible better estimations of operational capabilities and requirements.

Selection of terrain factors

The obvious advantages of a quantitative approach are its objectivity and the fact that mapping units can be rigorously defined. A more subtle, but equally important advantage is that quantitative factors offer the possibility of being manipulated mathematically in such a way that the effects of individual terrain factors acting in concert may be determined. In most instances such quantitative effects have evolved from studies aimed at determining terrain effects in special fields such as hydrology and agriculture. As a result, quantitatively expressed factors useful in presenting an aggregate or entire picture of terrain have not been explored to any great extent. Usually the process of quantitative analysis results in a multiplicity of quantitative measurements to express a simple descriptive qualitative term. Thus, the quantitative system gains in precision, but loses in simplicity. Quantitative terrain description has its limitation and should not be employed unless its contribution outweighs the complexities it introduces.

A major problem in developing the WES system of landscape classification was to choose simple descriptive terrain factors which could be measured and which describe a given landscape as completely as possible. There are many measurable properties relating to surface geometry that can be utilized in a quantitative system of terrain description. In fact, 37 such properties are employed by one analyst in describing fluvially eroded areas alone. Thus the problem is one of limiting the number of factors while still providing a reasonably complete picture of the terrain. Considerable effort was

spent in limiting the number of terrain factors while making sure that factors truly important in landscape description were not disregarded, and also in selecting and grouping terrain factors that, when considered in concert, are readily visualized and result in a minimum of cartographic complexity.

Of considerable importance in the selection of terrain factors is their "mappability" in poorly mapped or unmapped areas of the world. In other words, the factors chosen for mapping must be so chosen and so stratified that valid assumptions can be made concerning how they are to be mapped in areas where data are scarce. Thus, a knowledge of the basic rock type of an area often permits fairly accurate estimates of the depth of dissection, the density of deep drainageways, and whether the topographic highs are flat-topped or serrate. The general geologic structure often enables an evaluation of parallelism of the topographic forms and of relief and slope aspects. A knowledge of the geomorphic history and landform development of an area may permit the analyst to evaluate such terrain factors as areal extent of the topographic highs which rise above a plain or the slopes which are characteristic of these highs.

Selection of mapping units

Similarly, naturally occurring groupings or ranges of terrain factors played an important role in establishing the various mapping units. For example, detailed reports dealing with alluvial fans conclude that the slope of a fan is always less than 17.5%, and in the vast majority of cases, less than 10%. Studies of barchan dunes indicate that windward slopes range from 9 to 25%. These, and additional data indicated that valid boundaries between slope-mapping units could be set at approximately 10 and 25%. Use of such naturalistic breaks permitted maximum use of landform-terrain factor ties or associations in mapping areas where little quantitative or detailed information was available.

Availability of data was another determinant in establishing mapping units. The same units of breakdown had to be utilized in mapping all the world desert areas. Unless this system was adhered to in the entire mapping program, the mapping of one area would have no relation to that of another, and no comparisons could be made. It should be emphasized, however, that availability of data was not permitted to unduly restrict the number of units with which each terrain factor was mapped. Individual terrain factors were subdivided into units sufficiently detailed and restrictive to reasonably define a given landscape from both a military and geomorphic standpoint. Where these ranges could not be mapped from available data, inference or judgment based on soils, landforms, or other associations was relied on.

To summarize, landscape geometry factors were chosen for mapping on the basis of (a) their importance, individually, as basic

elements of a given landscape, (b) their capacity, when viewed in concert, to provide a reasonably complete picture of a given terrain, and (c) their "mappability" in poorly mapped areas of the world. The selection of mapping units for each of these landscape factors was based on such considerations as (a) naturalistic breaks, and (b) adaptability of the unit to precise and, wherever possible, to quantitative definition.

Method of Classification

A landscape or segment of landscape can be identified in terms of slope, relief, and dissection or slope spacing. Thus, describing an area as having gently sloping, moderately spaced hills rising to considerable heights above the surrounding plain gives a reasonable picture of the landscape. When a region is described as having hills with slopes ranging between 17.5 and 35%, spaced about 1000 ft apart, and rising to heights of 50 ft, a more quantitative and clearer picture of the landscape is provided. Therefore, assigning a reasonable numerical range to these three factors and cataloging various combinations of ranges of these three factors are logical steps in landscape definition. A less tangible but equally important property necessary to complete this definition is the spatial distribution of these three factors, called, in this system of classification, the plan-profile. To illustrate, consider a gently sloping plain dissected by a number of deep, narrow drainageways. This would be mapped as an area of a given range of slopes, relief, and slope spacing. Consider another gently sloping plain with a series of narrow dikes or ridges crossing it. This would be mapped with exactly the same ranges of slope, relief, and slope spacing, yet the disposition of features composing the landscape in each instance would be different. A profile of the two landscapes would appear as ‾\/‾‾\/‾‾\/‾ in the first instance, and as _/__/__/_ in the second. In addition, it is desirable to know whether the ridges or drainageways are parallel or intersecting, continuous or discontinuous; in other words, a plan view of the area is needed. The plan-profile thus becomes a necessary part of landscape definition.

Characteristic slope

A slope may be defined as a surface designated in terms of its deviation from the horizontal. The amount of deviation is commonly expressed as a rate of vertical rise per horizontal interval, as a percentage, or in degrees. Slopes in nature are characterized by an infinite number of such deviations from the horizontal, and to map these changes in slope some standard of generalization must be adopted. Characteristic slope, therefore, is defined in terms of a set standard of generalization. Primarily, this standard is the contour interval found on available map coverage, the contour interval that determines the resulting topographic picture or "envelope."

For example, a map with a contour interval of 200 ft gives a much more generalized topographic picture of a region than a map of the same area utilizing a 25-ft contour interval. The map with the smaller contour interval will indicate many more slopes than its 200-ft counterpart, and therefore, the characteristic or most frequently encountered slope would differ. It follows that, up to a point, the smaller the contour interval the truer the resulting picture of the surface. It is impractical, however, to consider slope breaks apparent only on maps with 1-, 2-, or 3-ft contour intervals. Besides the almost insurmountable problems inherent in mapping surfaces in such minute detail, this detail often obscures slopes of major importance generated by larger contour intervals. For the system described in this paper, it was found convenient to arbitrarily set the limiting scale of generalization as that defining landscapes and associated slopes generated by a 10-ft contour interval. Irregularities apparent only on maps with contour intervals less than 10 ft are considered as microrelief and, as such, mapped separately as a distinctive factor family.

Characteristic slope is defined as the narrow range of slopes that predominates or is most common within a region based on an examination of the surface generated by a 10-ft contour interval. The utilized stratification of characteristic slope is shown in fig. 1. The breaks or boundaries are primarily "naturalistic" in that they help to define certain commonly recurring desert surfaces. Unit 1A (0 to 1%) is typically associated with very flat surfaces such as playas; unit 1B (1 to 3-1/2%) often identifies the very gently tilted valleyward peripheries of alluvial fans or alluvial flats common in desert regions; unit 2 (3-1/2 to 10%) brackets the slopes typically formed by alluvial fans; unit 3 (10 to 25%) represents the normal range of slopes forming the windward sides of sand dunes and consequently forms the characteristic slope of most dune fields; unit 4 (25 to 50%) characterizes many hill regions and the upper break approximates the limit of many subdued "angle of repose" deposits such as talus. The 100% break between units 5 and 6 is quite arbitrary; however, the characteristic slope of mountainous regions rarely exceeds this value.

Characteristic relief

Relief may be defined as the maximum difference in elevation per unit area. Although this definition is adequate in areas of fairly high characteristic slope, it is inadequate in regions exhibiting low characteristic slope or poorly developed drainage. If, for example, we define relief as the maximum difference in elevation per square mile, the surface of an alluvial fan with a slope of approximately 10% could exhibit "relief" of over 500 ft. In such cases the depth of incision of the drainageways is the important relief consideration rather than difference in elevation per unit area. Similarly, in sand dune areas the important relief consideration, the height of the dune above the interdune troughs, is usually missed when relief is expressed as elevation differential per small unit area. Consequently,

if certain important considerations are to be properly emphasized, a flexible definition of relief is needed.

A dual definition or classification of relief was, therefore, utilized in the WES system. Characteristic relief is considered to be (a) the modal vertical distance from interfluve crest to the immediately adjacent flow line in low-slope (less than 10%) areas, and (b) the maximum difference in elevation per square mile in high-slope (more than 10%) areas. Fig. 1 shows the ranges of relief values used in the mapping system.

<u>Occurrence of slopes greater than 50%</u>

Slope occurrence provides a measure of dissection or what might be termed "landscape compartmentation." For example, consider a well scored surface of an alluvial fan. The characteristic slope of the fan approximates 7% and the modal depth of the washes is 1½ ft. As is usually the case, the wash-bank slopes are all steeper than 50%. In this case the landscape compartmentation consists of a series of flat-topped interfluves separated by pairs of steep slopes descending into narrow, shallow washes. Another type of compartmentation is exhibited in a field of complexly overlapping barchan dunes. The characteristic slope of the field falls between 10 and 25% (the windward slope of the dunes) and the modal relief is less than 50 ft. Here the landscape is "compartmented" by the steep (greater than 50%) slip-face slopes of the dunes. In contrast to the wash-scored alluvial fan surface, the steep slopes of the dune field do not occur in pairs. Consequently, in some cases it is desirable to describe compartmentation in terms of the frequency of occurrence of "compartmenting" slopes per unit of length, and in other cases in terms of average or modal distance between such slopes.

In the WES system, a compartmenting slope is considered to be any slope steeper than 50%. Here again the limit or boundary was established on the basis of naturalistic and military considerations. In desert regions most streams or wash banks and the surfaces of "angle of repose" deposits exceed 50%. This slope thus divides the landscape into compartments along such naturalistic breaks as stream banks, terrace escarpments, mountain slopes, dune slip faces, etc. Furthermore, except when wet, slopes less than 50% are of minor consequence from the standpoint of many military activities. Fig. 2 shows the ranges of occurrence values used in the mapping system.

<u>Characteristic plan-profile</u>

The three terrain factors discussed earlier are adequate measures of specific properties, but even taken in sum they fail to convey an impression of the geometry of the surface as a whole. It is possible, using any given combination of mapping units of these factors, to visualize a large number of quite different geometric configurations. Because overall configuration is vital to many military

activities, it is necessary to provide a descriptive fabric wherein the magnitude of slope, relief, and slope occurrence can be visualized.

Upon examination, it was determined that a minimum of four terrain factors was required to provide an adequate descriptive fabric. These four factors concern the spatial distribution and configuration in both plan and profile of the topographic highs and lows. The four factors selected are measures of: (a) the "peakedness" of the topographic highs; (b) the areal occupance of the highs; (c) the degree of elongation or planar shape of the highs; and (d) the orientation or degree of alignment exhibited by the highs.

It follows that for complete quantification of surface geometry the descriptive system should include four additional units, each indicating the distribution of one of the terrain factors mentioned above. However, the mental integration of these four factors into a visualization of the landscape is so difficult that they have been combined for the purposes of this study into a single composite terrain factor called the plan-profile. This has been done by classifying each of the four composite factors in such a way that, combined in the manner shown in fig. 2, they identify 24 basic variations of landscape configuration. Each of these 24 types, plus one other anomalous type, has been assigned a symbol and these types have been mapped as units.

Thus, the plan-profile is a composite terrain factor, and each component factor making up the composite is susceptible of quantitative treatment. It should be noted, however, that the final selection of the components of the plan-profile--even though each can be measured quantitatively--is a broad one; viz., the highs are either parallel or they are not, they are peaked or they are not, etc. Because of this broad stratification or classification, the choice of the plan-profile type can often be made by simple examination of an aerial photograph or a topographic map. It is only in those instances where one of the component factors, such as linearity, is doubtful that actual measurements must be made. The point is, that the decision as to whether the highs are linear or not can be made, wherever necessary, by quantitatively and objectively measuring them on topographic maps.

The dimensions of the landscape typified by the plan-profile are dependent upon the magnitude of relief and slope occurrence. For example, alluvial fans scored by steep-sided, shallow washes are mapped with the same plan-profile as extensive, high-standing, dissected plateaus. This is considered not only permissible but desirable, because with unrestricted dimensions, the plan-profile offers a convenient framework within which a knowledge of the values of slope, relief, and slope occurrence permits a readily assimilated mental image of the landscape.

Landscapes: [illegible] maps, surfaces defined by 100-ft contour interval [illegible] those defined by 10-ft contour interval maps. [illegible]

A landscape may be prepared by simply combining plan-profile, slope occurrence, slope, and relief terrain factors. Through superposition of the various maps, combinations of these factors evolve, each representing a distinctive landscape. As the number of possible combinations of the four factors is rather appalling, it was considered impractical, during early stages of the WES studies, to try to develop a scheme for delineating individual landscapes. Multiplying the number of units of breakdown within each factor (25 × 6 × 7 × 7) results in over 7000 mathematically possible combinations. Fortunately, however, nature has been far more selective, and superposition of the maps results in only 18 landscape types occurring at Yuma and only 78 in the entire North African Desert. [illegible]

Thus the combining of the four basic geometry or form factors has resulted in a convenient method for cataloging landscapes. The method is believed to be as simple and straightforward as possible. Any landscape can be designated by a combination of four number of number-letter symbols, each representing a particular range of values of plan-profile, slope occurrence, slope, and relief. The combination shown in the upper diagram in fig. 3 (1L//-4-1b-2), for example, defines a plain with a slope of 1 to 3-1/2%, dissected by roughly parallel washes from 10 to 50 ft deep spaced from 1000 to 5000 ft apart. The lower diagram also defines a landscape type--in this instance type 5L//-2-4-6: a parallel ridge area with ridges from 2 to 10 miles apart, their heights ranging between 1000 and 400 ft, and their characteristic slopes between 25 and 50%.

The figure also illustrates conditions under which a dual or complex classification is mapped--the gross-component complex--which a moment's reflection will reveal as being necessary. Each landscape is composed of smaller landscapes and is, in turn, part of a larger or next order landscape. The lower diagram is referred to as a gross landscape. It is determined utilizing a 35-mile-diameter sampling circle, and is the landscape generated by a 100-ft contour interval. The upper diagram illustrates the restrictive landscape, a landscape determined by utilizing a 1-mile-diameter sampling circle with a 10-ft contour interval. Relief less than 10 ft falls into the category of microrelief or surface roughness. This is a convenient, if arbitrary, subdivision of terrain envelopes which has turned out to be of great value in the problem of landscape mapping. Wherever a gross-component relation exists, such as that shown in fig. 3 where the upper landscape is a smaller, restrictive, or component part of a larger or gross landscape, each is mapped with an appropriate symbol and identified.

Preliminary studies indicate that valid and worthwhile inferences can be made of the landscape geometry of a particular region from maps employing a 500-ft contour interval. These studies indicate that reasonably valid relations can be established among surfaces

defined by such maps, surfaces defined by 100-ft contour interval maps, and those defined by 10-ft contour interval maps. Detailed studies are needed to graph and compare geometry factor values of selected regions determined or mapped at different contour intervals and scales. Relations among the hierarchy of surface envelopes could then be computed for all areas mapped, and hypotheses derived and tested to explain significant variations in these relations--very possibly dependent upon lithology and climate.

Applications

Although the system of landscape classification described in this paper was developed for desert terrain, it has been used with reasonably good results in temperate and tropical areas. Some changes in the mapping units used for each of the factors may be necessary to reflect more closely naturalistic breaks common to humid areas. To date, the system has been used principally in developing desert analogs of the terrain at the Research and Development Test Facility at Yuma. The purpose of this analog development is to assess the suitability of Yuma as a desert testing site for men and materiel. After the method has been applied to the world deserts under consideration, it may be found that the Yuma Test Station lacks certain ranges or combinations of terrain-factor ranges found in other desert areas. Application of the technique to the desert of western United States should permit an evaluation of areas within the United States that may be more analogous to aggregate world desert conditions than the Yuma area, or which, when considered with Yuma, will cover a much more representative range of desert terrain. Such areas could well be utilized as supplementary testing sites. (It should be remembered that analog development and the study of the effect of terrain on military activities in general must be based on all the terrain factor families, not solely on the landscape geometry factors discussed in this paper.)

The determination of terrain analogs is only a preliminary step to the important goal of predicting quantitative impacts of terrain on individual military activities. These activities are each concerned with different terrain factors and with varying degrees of refinement of the mapping units within each factor. Thus, after the various terrain factors have been modified to meet the needs of a particular problem, tests can be conducted in areas characterized by distinctive combinations of the devised mapping units. The important point is that the same system of characterizing the testing environment be used in all areas so that tests in one area can be related specifically to tests in another.

As an example, a comprehensive test program concerned with developing methods for predicting soil moisture for trafficability purposes is presently being undertaken by the Army Mobility Research Center of the WES. Soil-moisture-prediction sites are scattered throughout the United States and other parts of the world. One of the parameters affecting soil-moisture variation which is being considered is

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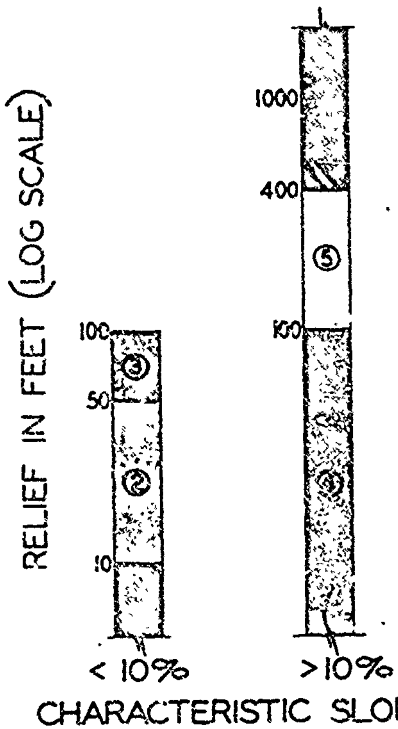
the landscape type within which each site falls. Similarly, the landscape classification is being considered for selection of parachute-drop test sites and for estimating the impact of varying terrain types on airfield construction effort.

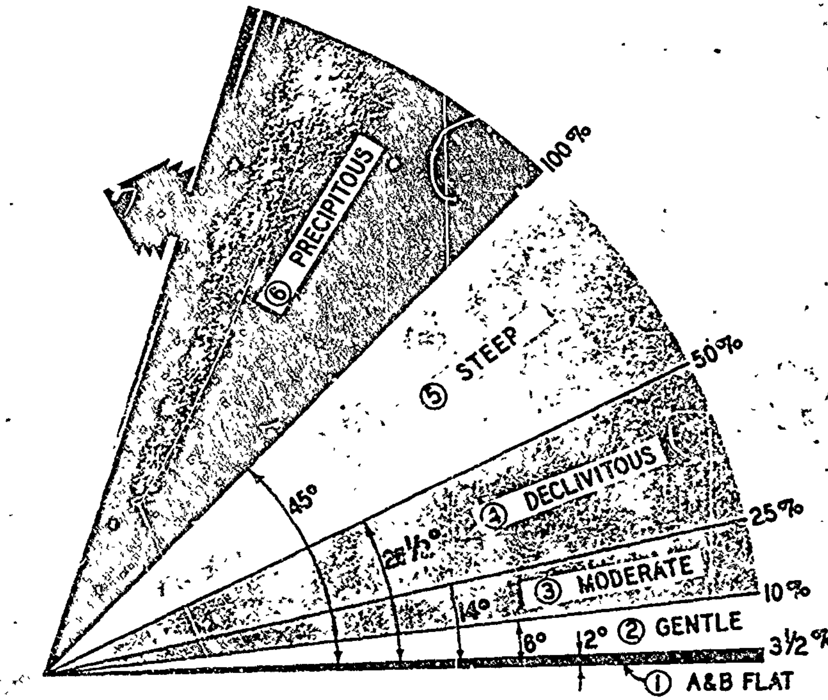
An interesting application presently (fiscal years 62-63) under way is the selection of courses at the Yuma Test Facility for testing the mobility of the Overland Train, a logistical cargo carrier built for the Transportation Corps and designed for cross-country movement. It has 10-ft-diameter tires, a length of 567 ft, and consists of 37-ft-long individual carriers capable of hauling a total of 136 tons. A number of test courses, approximately 200 ft wide and totaling more than 50 miles in length, were selected for the test runs. These courses cross terrain that is areally significant in deserts of North Africa, the Middle East, and South Central Asia. The test program is designed to study the effects of various types of terrain on the cross-country performance of the Overland Train. Performance data to be collected along each terrain type will include braking, steering, and driving energy; effects of vertical and horizontal acceleration on a cargo car and a supporting axle; fuel consumption; and dust densities developed. It is anticipated that grouping certain of the terrain mapping units within selected terrain factors will be required to account for the performance data. Conversely, it may be found that performance variations will occur in response to conditions within a single mapping unit. For example, it may be found that a certain slope value which lies within one of the established slope mapping units is critical in the performance of the Overland Train. In this event, it may be necessary to subdivide the existing mapping units in order to adequately describe the effects of terrain on performance. Ultimately, these data will be employed to construct a terrain effects map, in which ranges of effects on the Overland Train will be used as mapping units.

Summary and Conclusions

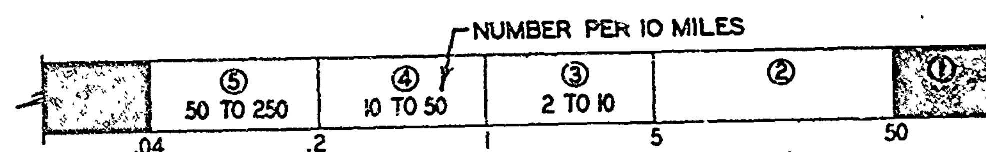
Landscape description to date has been almost entirely subjective, or where it is quantitative, often designed with a specific and fairly limited purpose in mind. The system outlined in this paper approaches an objective framework on which to hang terrain description wherever and for whatever purpose it is needed: determining the suitability of desert testing sites, assessing airfield construction difficulties, soil-moisture site classification, Overland Train route selection, to mention important military activities to which the method is presently being applied. Further, this framework is in the form of specific and definable physical properties or dimensions. No claims are made that this landscape classification is the ultimate in either sophistication or utility. Studies now under way, for example, promise considerable improvement in quantifying the classification. But the system as outlined is a possible approach and, it is hoped, will help to bring some order into the chaos of subjectivity with which landscape and terrain description, in general, must contend.



CHARACTERISTIC RELIEF



CHARACTERISTIC SLOPE



OCCURRENCE OF SLOPES STEEPER THAN 50%

FIGURE 1

CHARACTERISTIC PLAN-PROFILE

The characteristic plan-profile is the most commonly found plan-profile within a region. It may be either gross or restrictive. A gross plan-profile is one that can be subdivided into two restrictive component plan-profiles each exhibiting relief of a lower order than the gross plan-profile. Random sampling with circles 35 miles in diameter is used in determining the gross profile. Random sampling with circles 1 mile in diameter is used to determine the restrictive plan-profile. Local relief of less than 10 feet is not considered.

LEGEND

Highs* Occupy:	Highs are → / Schematic Profile ↓	Schematic Plan	Non-linear and Random	Linear and Random	Non-linear and Parallel	Linear and Parallel
>60% of area	Flat-topped		1	1 L **	1// ***	1L //
40-60% of area	Flat-topped		2	2L	2 //	2L //
<40% of area	Flat-topped		3	3L	3 //	3L //
>60% of area	Crested or Peaked		4	4L	4 //	4L //
40-60% of area	Crested or Peaked		5	5L	5 //	5L //
<40% of area	Crested or Peaked		6	6L	6 //	6L //
No pronounced highs or lows			7			

REPRESENTATIVE PLAN-PROFILES

Each of the following block diagrams illustrates a landscape representative of a specific plan-profile type. It should be emphasized that, within the defined limits of each type, a wide variety of landscape configurations are possible.

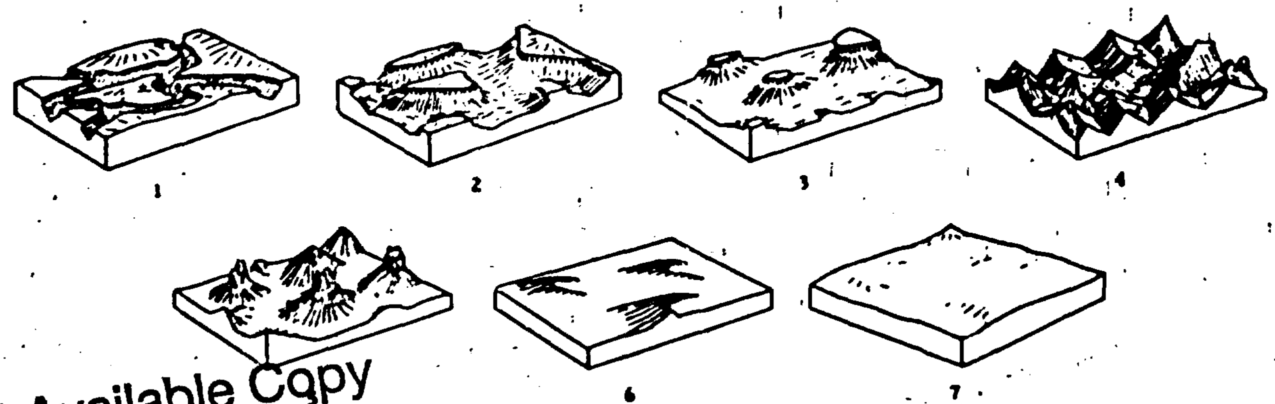
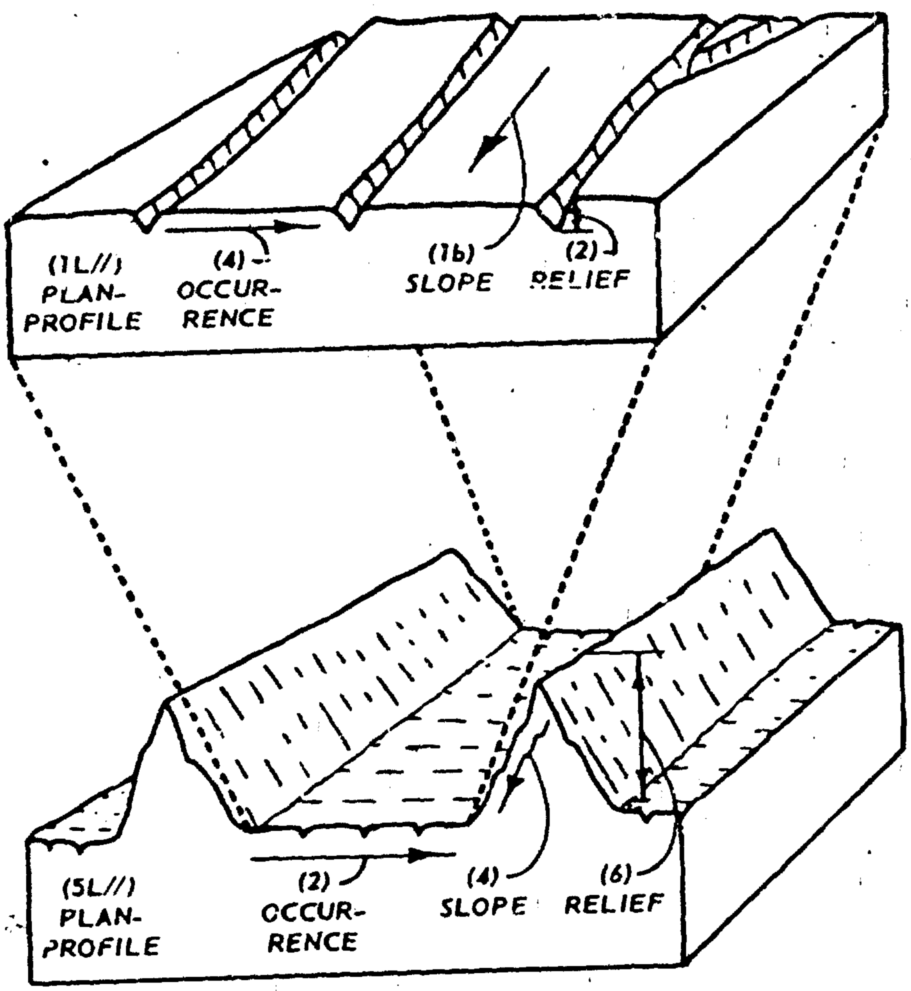


FIGURE 2

COMPONENT LANDSCAPE

A PLAIN WITH A 1 TO 3.5% SLOPE DISSECTED BY ROUGHLY PARALLEL WASHES FROM 10 TO 50 FT DEEP, SPACED FROM 1000 TO 5000 FT APART



GROSS LANDSCAPE

A PARALLEL RIDGE AREA WITH THE RIDGES FROM 2 TO 10 MILES APART, THEIR HEIGHT RANGING BETWEEN 400 AND 1000 FT, AND THEIR CHARACTERISTIC SLOPE BETWEEN 25 AND 50%

FIGURE 3